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Description

This invention relates to the utilization of thermal energy.

Over the past ten years considerable research has been carried out with a view to making use of thermal energy available from geological sources. It will be understood that many of these sources provide an inlet temperature/pressure which is too low to ensure satisfactory operation of most conventional power generating machines such as turbines. Moreover, even if these basic parameters are suitable for use in a turbine, the working fluid is frequently contaminated so that deposits are formed with resultant reduced efficiency and actual damage to the turbines.

With a view to overcoming the basic problems of relatively low grade heat, proposals have been put forward, for example in U.S. Patent Specification 3,751,673 and U.K. published Application 2114671, in which relatively low grade heat is utilized for the production of power with the aid of one or more helical screw expanders. Such expanders, initially developed by Lysholm, have the advantage that they can tolerate working fluids which are liable to cause deposits, because close tolerances are not critical to successful operation and deposits from the working fluid may even be beneficial. However, the use of geothermal water as proposed in the U.S. specification has the substantial disadvantage that the properties of water and steam necessitate the use of a very large machine in order to produce the required power. The specification of the published United Kingdom application is primarily concerned with the use of such machines, but employing in place of geothermal water a working fluid which has properties more suited to use in relatively small helical screw expanders.

In the cycle proposed in U.K. patent application 2114671, the inlet temperature of the working fluid is preferably fairly low, the geothermally-heated water being at a temperature of the order of 100°C. Probably the greatest benefits will arise from use of geothermally heated water at temperatures of the order of 120°C. At higher temperatures the efficiency advantage of the cycle disclosed in the United Kingdom published specification diminishes but is not eliminated because conventional supercritical Rankine cycles become more attractive in the matching of the boiler heating characteristics to the heat source at higher temperatures. Even at quite high temperatures, of the order of 300°C, the advantage remains.

US—A—4 463 567 discloses a system wherein a fluid exhibits a regressive vapour dome in a T-S diagram. To enable satisfactory operation, a two-phase nozzle receives the fluid in a pressurized and heated liquid state and expands the received liquid into saturated or super-heated vapour state. The turbine apparatus receives the saturated or super-heated vapour to convert the kinetic energy into power. As will be readily understood, the two-phase nozzle does not in itself generate any power but merely renders the working fluid suitable for use in a turbine or other appropriate apparatus. Another problem with this prior proposal is that the two-phase nozzle will produce a very high efflux velocity and velocity compounding will therefore be necessary with resultant low turbine efficiency.

The general objective of the present invention is to provide a method and apparatus rendering possible more efficient use of geothermal and other low grade sources.

According to the present invention there is provided a method of utilizing thermal energy comprising the steps of heating a first working fluid by pumping through a hot dry rock or other low grade heat source, supplying the heat from the first working fluid by heat-exchange to a more volatile, second, working fluid which passes through a trilateral cycle comprising substantially adiabatically pressurizing the said second working fluid prior to the heat input from the first working fluid, substantially adiabatically expanding the hot pressurized second working fluid by flashing in a helical screw expander or other expansion machine capable of operating effectively with wet working fluid and of progressively drying said fluid during expansion to produce a substantially saturated vapour, characterized by passing the exhaust second working fluid in substantially saturated vapour form from the screw expander through a turbine wherein the second working fluid is further dried, condensing the second working fluid exhausted from the turbine and returning it to receive heat from the first working fluid by heat-exchange.

The trilateral cycle referred to has been described and claimed in our co-pending published British patent application 2114671. An important distinguishing aspect of the present invention as broadly defined is that the working fluid is chosen such that the expansion from saturated liquid to saturated vapour is carried out in a screw expander with or without preflashing and that further expansion of the vapour is then carried out in a turbine of conventional design such as is used in Rankine systems. The second working fluid exhausted from the helical screw expander may be dry or wet and in the latter event drying will be completed in the inlet nozzles of the turbine.

Further according to the present invention there is provided apparatus for utilizing thermal energy by the method in accordance with the invention comprising means for pumping a first working fluid through a hot dry rock or other single phase low grade heat source, heat-exchange means for supplying the heat from the first working fluid to a more volatile, second, working fluid, means, upstream of the heat-exchange means, for substantially adiabatically pressurizing the said second working fluid, a helical screw expander capable of operating effectively with wet working fluid and of progressively drying said fluid during expansion, the expander being connected to receive the second working fluid from the heat-exhange means and serving to expand substantially adiabatically the hot pressurized second working fluid by flashing, characterized by a turbine connected to receive the second working fluid exhausted from the expander, and a condenser for the second working fluid exhausted from the turbine, the different parts of the apparatus working with the second working fluid being so dimensioned and arranged that the second working fluid is in the form of substantially saturated vapour when it is exhausted from the helical screw expander and said second working fluid is further dried in the turbine.

Exhaust heat from the turbine may be employed for industrial or district heating.

The invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a temperature-entropy diagram illustrating a trilateral cycle incorporating two expansion regimes; and

Figure 2 is a diagram illustrating the main component parts of a plant in accordance with the invention.

Referring now to Figure 1 the temperature-entropy diagram illustrates the trilateral cycle including the saturation envelope for the working fluid selected (referred to in more detail hereinafter) and the state points 1 to 6 of the working cycle. Substantially adiabatic liquid pressurization takes place 1—2, heating and evaporation 2—3, first stage, substantially adiabatic expansion in a helical screw expander 3—4, second stage, substantially adiabatic expansion in a vapour turbine 4—5, de-superheating 5—6 and condensing 6—1. The heating medium cooling path is shown at 7—8 and follows the heating and evaporation stage 2—3. The heat transfer from the thermal source is effected at approximately constant pressure substantially to the boiling point of the selected working fluid.

Figure 2 shows highly diagrammatically main components of a plant operating the cycle of Figure 1. A recirculating pump 10 serves to pump a first working fluid through fragmented hot dry rock and through the hot pass of a heat-exchanger 11. A second, more volatile, working fluid is circulated through the cold pass of heat-exchanger 11 by a feed pump 13 and the boiling, volatile, working fluid then passes through a helical screw expander 14, at the exhaust of which the second working fluid is usually dry and thus suitable for use in a conventional vapour turbine 15. The exhaust from the turbine passes through a condenser 16. The dry saturated state of the second working fluid is achieved by appropriate selection of the fluid itself and the flashing which takes place in the screw expander 14. Pre-flashing, that is, upstream of the inlet to the screw expander is advantageous with certain working fluids and conditions. If the exhaust second working fluid from the screw expander is not fully dry, then the fluid can be dried in nozzles upstream of the first or possibly sole rotor stage.

With the circuit illustrated in Figure 2, it is possible to employ hot dry rock as a heat source at temperatures of the order of 250°C. The trilateral Rankine cycle combination can use a working fluid such as monochlorobenzene (T_c=359°C), Thermex (Registered Trade Mark) and similar working fluids in which modification the complication of separate condensers and circulating pumps can be avoided. Thermex is a mixture of diphenyl and diphenyl oxide and has a high critical point. Dichlorobenzene and Toluene are other possible working fluids.

Although hot dry rock is the preferred heat source, a high temperature and high pressure geothermal source can also be used. It will, of course, be understood that the helical screw expander and the Rankine cycle turbine will be coupled to a shaft power user such as an electricity generator.

In broad terms the circuits in accordance with the invention are capable of good heat recovery even from a grade of heat which could otherwise be used only for district heating and other applications where no shaft power is required. This advantage is particularly emphasized by the aspects of the invention which combine a trilateral cycle with a conventional Rankine cycle, the latter being able to make use of a useful proportion of the available liquid sensible heat.

In relation to the embodiments of the invention, helical screw expanders are referred to but it will be appreciated that, in certain instances, rotary vane expanders can be used as an alternative. It follows that wherever reference is made herein to "helical screw expanders" a rotary vane expander can be substituted. Again, for certain aspects of the invention the geo-thermal, hot rock, source can be replaced by an equivalent heat source within a similar temperature range.

A helical screw expander of small size has been tested when making use of an organic fluid and an adiabatic efficiency of 71% has been attained. With larger sizes such as would be used in practice appreciably higher efficiencies can be expected. This contrasts with efficiencies in the range 55—50% when using two phase, water/stream as the working fluid.

Claims

1. A method of utilizing thermal energy comprising the steps of heating a first working fluid by pumping through a hot dry rock or other low grade heat source, supplying the heat from the first working fluid by heat-exchange to a more volatile, second, working fluid which passes through a trilateral cycle comprising substantially adiabatically pressurizing the said second working fluid prior to the heat input from the first working fluid, substantially adiabatically expanding the hot pressurized second working fluid by flashing in a helical screw expander (14) or other expansion machine capable of operating effectively with wet working fluid and of progressively drying said fluid during expansion to produce a substantially saturated vapour, characterized by

passing the exhaust second working fluid in substantially saturated vapour form from the screw expander through a turbine (15) wherein the second working fluid is further dried, condensing the second working fluid exhausted from the turbine and returning it to receive heat from the first working fluid by heat-exchange.

2. A method according to claim 1, characterized in that the second working fluid is monochlorobenzene, dichlorobenzene or toluene.

3. Apparatus for carrying out the method of claim 1, comprising means (10) for pumping a first working fluid through a hot dry rock or other single phase lower grade heat source, heat-exchange means (11) for supplying the heat from the first working fluid to a more volatile, second, working fluid, means, upstream of the heat-exchange means, for substantially adiabatically pressurizing the said second working fluid, a helical screw expander (14) capable of operating effectively with wet working fluid and of progressively drying said fluid during expansion, the expander (14) being connected to receive the second working fluid from the heat-exhange means and serving to expand substantially adiabatically the hot pressurized second working fluid by flashing, characterized by a turbine (15) connected to receive the second working fluid exhausted from the expander, and a condenser (16) for the second working fluid exhausted from the turbine, the different parts of the apparatus working with the second working fluid being so dimensioned and arranged that the second working fluid is in the form of substantially saturated vapour when it is exhausted from the helical screw expander (14) and said second working fluid is further dried in the turbine (15).

4. Apparatus according to claim 3 characterized in that the helical screw expander (14) is replaced by a rotary vane expander.

Patentansprüche

1. Verfahren zur Nutzung thermischer Energie, mit den Verfahrensschritten:

Erhitzen eines ersten Arbeitsfluids, indem es durch ein heißes trockenes Gestein oder eine andere Wärmequelle niedriger Temperatur gepumpt wird;

Zuführen der Wärme des ersten Arbeitsfluids zu einem flüchtigeren, zweiten Arbeitsfluid, das einen dreiseitigen Zyklus durchläuft, der ein im wesentlichen adiabatisches unter Druck setzen des zweiten Arbeitsfluids vor dem Wärmezuführung von dem ersten Arbeitsfluid, ein im wesentlichen adiabatisches Expandieren des heiß zusammengedrückten zweiten Arbeitsfluids durch schnelles Entspannen in einer gewundenen schraubenförmigen Expansionseinrichtung (14) oder einer anderen Expansionsmaschine, die effektiv mit einem nassen Arbeitsfluid arbeiten kann, und das Fluid während der Expansion fortschreitend trocknen kann, um einen im wesentlichen gesättigten Dampf zu erzeugen, umfaßt, gekennzeichnet durch,

Hindurchtreten des als im wesentlichen gesättigter Dampf aus der schraubenförmigen Expansionseinrichtung austretenden zweiten Arbeitsfluids durch eine Turbine (15), wobei das zweite Arbeitsfluid weiter getrocknet wird,

Kondensieren des zweiten aus der Turbine ausgetretenen Arbeitsfluids und

Zurückfließen des Arbeitsfluids, um durch Wärmeaustausch Wärme von dem ersten Arbeitsfluid zu empfangen.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das zweite Arbeitsfluid Monochlorbenzen, Dichlorobenzen oder Toluen ist.

3. Vorrichtung zur Durchführung des Verfahrens nach Anspruch 1, mit

einer Einrichtung zum Pumpen eines ersten Arbeitsfluids durch ein heißes Trockengestein oder eine andere einphasige Wärmequelle von niedriger Temperatur,

einer Wärmetauschvorrichtung (11) zum Zuführen der Wärme von dem ersten Arbeitsfluid zu einem flüchtigeren zweiten Arbeitsfluid,

einer Einrichtung, stromaufwärts von der Wärmeaustauscheinrichtung, zum im wesentlichen adiabatischen Zusammenpressen des zweiten Arbeitsfluids,

einer gewundenen schraubenförmigen Expansionseinrichtung (14), die effektiv mit dem nassen Arbeitsfluid arbeiten und das Fluid während der Expansion zunehmend trocknen kann,

wobei die Expansionseinrichtung (14) zum Empfang des zweiten Arbeitsfluids von der Wärmeaustauschvorrichtung vorgesehen ist und zum im wesentlichen adiabatischen Ausdehnen des heiß zusammengepreßten zweiten Arbeitsfluids durch schnelles Entspannen dient,

gekennzeichnet durch

eine Turbine (15), die zum Empfang des zweiten aus der Entspannungsvorrichtung austretenden Arbeitsfluids vorgesehen ist, und eine Kondensiereinrichtun (16) für das zweite, aus der Turbine austretende Arbeitsfluid, wobei die unterschiedlichen Teile der Vorrichtung, die mit dem zweiten Arbeitsfluid arbeiten, derart dimensioniert und angeordnet sind, daß das zweite Arbeitsfluid im wesentlichen in Form eines gesättigten Dampfes vorliegt, wenn es aus der gewundenen schraubenförmigen Expansionseinrichtung (14) ausgelassen wird, und das zweite Arbeitsfluid in der Turbine weiter getrocknet wird.

4. Vorrichtung nach Anspruch 3, dadurch gekennzeichnet, daß die gewundene schraubenförmige Expansionseinrichtung durch eine Drehflügelexpansionseinrichtung ersetzt ist.

Revendications

1. Procédé d'utilisation d'une énergie thermique, comprenant les phases suivantes: le chauffage d'un premier fluide actif par pompage à travers une roche sèche chaude ou une autre source de chaleur de faible qualité, l'alimentation de la chaleur venant du premier fluide actif par échange de chaleur à un second fluide actif plus volatil, qui traverse un cycle trilatéral comprenant

la mise sous pression essentiellement adiabatique du second fluide actif susdit avant l'apport de chaleur depuis le premier fluide actif, la détente essentiellement adiabatique du second fluide actif sous pression chaud par une vaporisation flash dans un détendeur à vis hélicoïdale (14) ou autre machine de détente capable de fonctionner efficacement avec un fluide actif humide et de sécher progressivement ce fluide durant la détente pour produire une vapeur essentiellement saturée, caractérisé par le passage du second fluide actif d'échappement sous forme d'une vapeur essentiellement saturée depuis le détendeur à vis à travers une turbine (15) où ce second fluide actif est encore séché, la condensation du second fluide actif s'échappant de la turbine et son retour pour recevoir de la chaleur depuis le premier fluide actif par échange de chaleur.

2. Procédé suivant la revendication 1, caractérisé en ce que le second fluide actif est du monochlorobenzène, du dichlorobenzène ou du toluène.

3. Appareil pour la mise en oeuvre du procédé suivant la revendication 1, comprenant un dispositif (10) destiné à pomper un premier fluid actif à travers une roche sèche chaude ou une autre source de chaleur à simple phase, de plus basse qualité, un dispositif d'échange de chaleur (11) destiné à alimenter la chaleur provenant du premier fluide actif à une second fluide actif, plus volatil, un dispositif prévu en amont du dispositif d'échange de chaleur pour mettre sous une pression essentiellement adiabatique le second fluide actif susdit, un détendeur à vis hélicoïdale (14) capable d'opérer de façon efficace avec un fluide actif humide et de sécher progressivement ce fluide durant la détente, le détendeur (14) étant relié de manière à recevoir le second fluide actif depuis le dispositif d'échange de chaleur et servant à détendre de façon essentiellement adiabatique le second fluide actif sous pression chaud par une vaporisation flash, caractérisé par une turbine (15) connectée de manière à recevoir le second fluide actif s'échappant du détendeur, et un condenseur (16) pour le second fluide actif s'échappant de la turbine, les différentes parties de l'appareil opérant avec le second fluide actif étant dimensionnées et agencées de manière que le second fluide actif soit sous la forme d'une vapeur essentiellement saturée lorsqu'il s'échappe du détendeur à vis hélicoïdale (14), le second fluide actif étant encore séché dans la turbine (15).

4. Appareil suivant la revendication 3, caractérisé en ce que le détendeur à vis hélicoïdale (14) est remplacé par un détendeur à aube rotative.

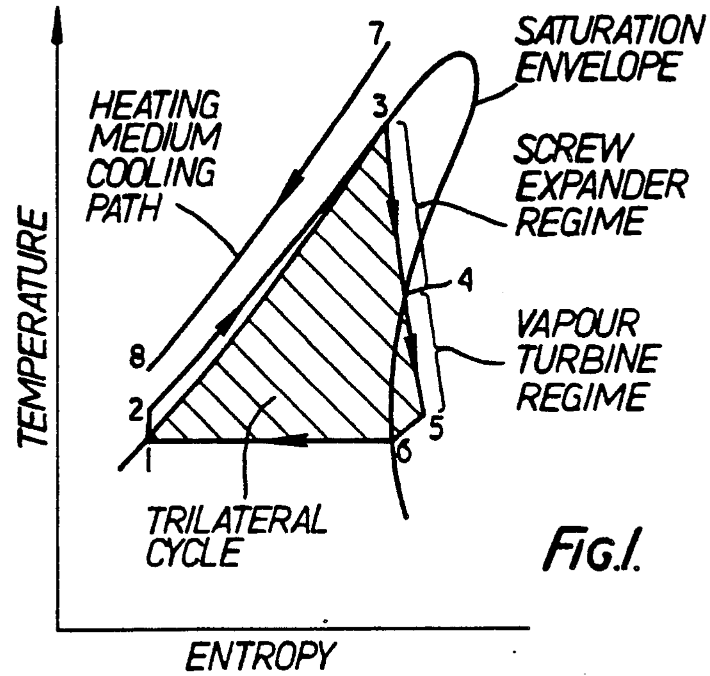
TEMPERATURE
ENTROPY
7
SATURATION ENVELOPE
HEATING MEDIUM COOLING PATH
3
SCREW EXPANDER REGIME
4
VAPOUR TURBINE REGIME
8
2
5
1
6
TRILATERAL CYCLE

FIG.1.

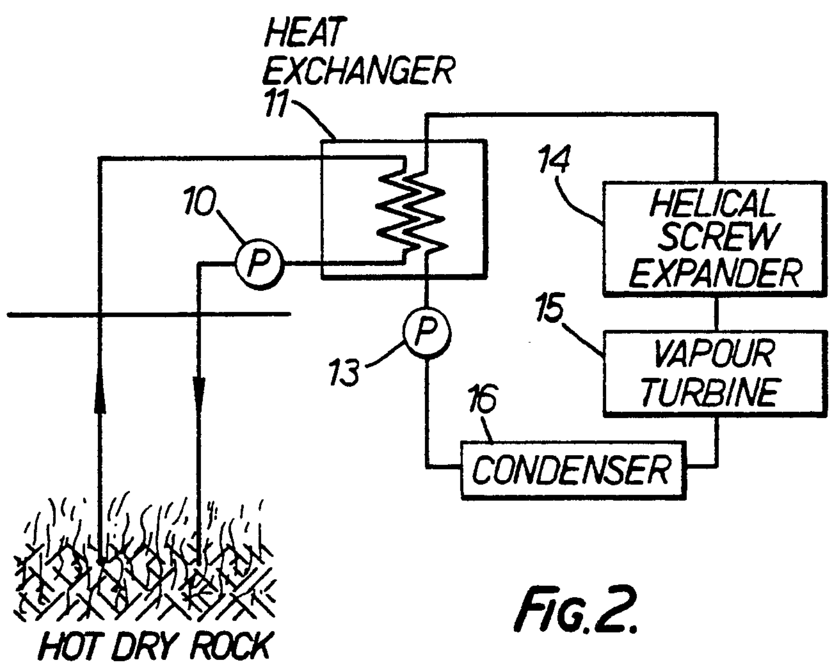
HEAT EXCHANGER
11
10
P
14
HELICAL SCREW EXPANDER
15
VAPOUR TURBINE
P
13
16
CONDENSER
HOT DRY ROCK

FIG.2.